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RVM versus PDC Methods for Insulations' Conductivity and Moisture Content Monitoring

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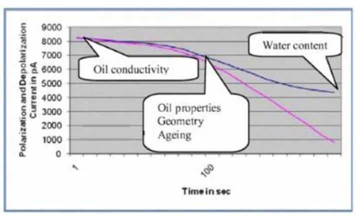
Graphical abstract



Abstract

Degradation due to ageing is a major concern for the life span of high voltage insulation. In maintaining the insulation system's performance, it is crucial to monitor the insulation condition as it contributes to the whole system's efficiency and safety. Many diagnostic methods have been introduced, and in use for monitoring the condition of insulation. Measurement and analysis in either frequency or time domain. Condition-based monitoring (CBM) is in growing interest lately, compared to time-based monitoring due to the increasing population of aged insulators being utilized in existing power systems. Time-based monitoring has then been integrated with CBM. CBM's ability to enhance reliability, improve safety and reduce hazard of a system has been recognized by many researchers and utilities. This paper presents the study and comparison of two time domain CBM techniques namely the polarization and depolarization current (PDC) measurement and return voltage measurement (RVM). Findings of previous researches on determining the insulator's moisture content and conductivity by both methods were reviewed. Moisture content and conductivity affect the dielectric response of the insulation material. Thus, condition of the insulation system can be determined based on these two characteristics.

Keywords: Degradation; PDC; RVM; moisture content; conductivity

Abstrak

Degradasi akibat penuaan merupakan kebimbangan utama bagi jangka hayat penebat voltan tinggi. Bagi mengekalkan prestasi sistem penebat, adalah penting untuk memantau keadaan penebat kerana ia menyumbang kepada kecekapan dan keselamatan keseluruhan sistem. Banyak kaedah diagnostik telah diperkenalkan, dan digunakan untuk memantau keadaan penebat. Pengukuran dan analisis adalah dalam domain frekuensi atau domain masa. Pemantauan berasaskan keadaan (CBM) semakin meningkat sejak kebelakangan ini, berbanding dengan pemantauan berasaskan masa kerana peningkatan umur penebat yang digunakan dalam sistem kuasa yang sedia ada. Pemantauan berasaskan masa kemudiannya telah disepadukan dengan CBM. Keupayaan CBM untuk meningkatkan kebolehpercayaan, meningkatkan keselamatan dan mengurangkan bahaya di dalam sistem telah diiktiraf oleh ramai penyelidik dan utiliti. Kertas kerja ini membentangkan kajian dan perbandingan dua teknik CBM domain masa iaitu pengukuran arus polarisasi dan depolarisasi (PDC) dan pengukuran pulangan voltan (RVM). Hasil penemuan daripada penyelidikan sebelum ini dalam menentukan kandungan lembapan dan kekonduksian penebat oleh kedua-dua kaedah ini juga dikaji Kandungan lembapan dan kekonduksian akan mempengaruhi tindak balas dielektrik dalam bahan-bahan penebat. Dengan itu, keadaan sistem penebat boleh ditentukan berdasarkan kedua-dua
ciri tersebut.

Kata kunci: Degradasi; PDC; RVM, kandungan lembapan; kekonduksian

■1.0 INTRODUCTION

Condition-based monitoring also known as condition based maintenance (CBM) differs from the time-based monitoring (TBM), whereby CBM enables prediction of required maintenance. It is conducted due to the degrading insulation condition of high voltage equipments under continuous high voltage stress. The predictive maintenance is performed after one or more indicators show degraded condition of the equipment's insulation. Popular methods in assessing the condition of the insulation include polarization and depolarization current (PDC) measurement as well as return voltage measurement (RVM). Time domain measurements based on PDC and RVM has gained significant importance over the last ten years. Time domain **measurement** is been characterized by the application of step voltage to the test object [1]. PDC and RVM is the dielectric testing method in determining the condition of insulation system. According to Saha *et al.* [2], this time domain dielectric response measurement methods is simple to perform and also provide the adequate relevant information about the condition of oil/paper insulation. Coupled with computer-aided technique, it is capable to record and process large amounts of data as well as to improve the possibilities in analyzing the insulation's condition for both methods.

The ageing statusand moisture content of the insulation can be determined from measurements of PDC and RVM [1]. PDC that is known as non-destructive dielectric response method is able to determine the conductivity and moisture content in high voltage insulation system. Findings from the previous research will be discussed in this paper. The focus is on PDC method as an alternative to the conventional RVM method.

2.0 EXPERIMENTAL

This paper reviewed two condition-based monitoring methods: PDC and RVM. PDC is measured in the current while voltage been measured in RVM. Both methods have specific parameters to be identified such as charging/discharging time and test voltage. The paper is focusing on application of both methods in diagnosing solid and liquid type of insulator. These parameters then been investigated on the effects of moisture content and the conductivity level.

The principle of measurement in PDC is based on the application of a DC voltage across a test object for a period of time, in which current will flow from the polarization process in the test object with different time constants. This current depends on the insulation material and its conductivity. Figure 1 shows the basic circuit in measuring PDC. This current is called as polarization current. Polarization current is depends on two parts; first part respected to conductivity of test object while the other part is related to the activation of the different polarization processes that happened within the test object [3]. Polarization current is representing by Equ. 1.

$$i_p(t) = C_0\, U_0\, [(\sigma/\varepsilon_0) + f\,(t)] \qquad (1)$$

C_0 is geometric capacitance, U_0 is charging voltage, σ is DC conductivity, ε_0 is vacuum permittivity (8.854×10^{-12} F/m) and $f\,(t)$ is response function. Next, the voltage is removed and the test object is short-circuited. The activation from the previous polarization process now gives rise to the discharging current in the opposite direction. This process in which the current flows in the relaxing state is called depolarization current [2-6]. Depolarization current represented in Equ. 2.

$$i_d(t) = -\, C_0\, U_0\, [(f(t)) - f(t\text{-}t_c)] \qquad (2)$$

Figure 2 shows the polarization current as well as the depolarization current in an amount of time after been applied the voltage dc. t_p is polarization time or known also as charging time while t_d is depolarization time or discharging time. DC conductivity then can be estimated from the measurement of polarization and depolarization current. It can be expressed by the Equ. 3 if the test object is charging in the sufficiently long time until $f\,(t\text{-}t_c) \equiv 0$. Thus, conductivity can be expressed as Equ. 3 [3].

$$\sigma \approx (\,\varepsilon_0 / C_0 U_0\,)\,[\,i_p(t) - i_d(t)\,] \qquad (3)$$

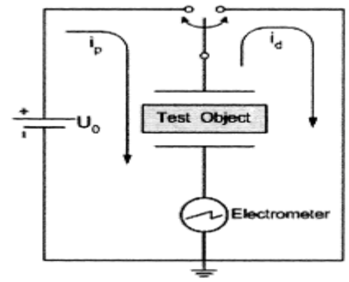


Figure 1 Basic PDC measuring circuit

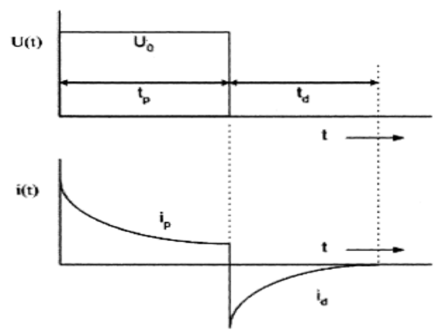


Figure 2 Waveform of polarization and depolarization currents

Saha *et al.* [2] stated that depolarization current is depends on several factors. It is including the geometry, moisture content, conductivity and other ageing conditions of oil-paper composite insulation system. Figure 3 describes the parameters that influence the curves of PDC.

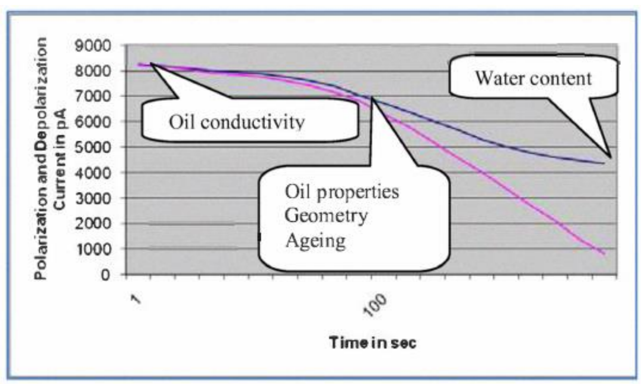


Figure 3 Oil Conductivity, oil properties, geometry, ageing and water content influence on the PDC curves [4]

PDC curves in Figure 3 showed that oil conductivity can be measured by the initial part of curves. Higher conductivity leads to higher current value [4]. Whilst water content can be measured in an amount of time that shown in final part of the PDC curves. Ilstad *et al*. [1] described that the shorter times is influenced by oil conductivity, whereas the conductivity of solid will be affected the final parts of PDC. It is called the nature of PDC.

The basic principle of RVM is charging the sample for a long period of time, t_c. Then, the sample is isolated from the HV source and short-circuited for a shorter period of time, t_d. Then the short circuit is disconnected, and the charge bounded by the polarization process will turn into free charges. Figure 3 describes the principle of return voltage measurement in terms of circuit and waveform. This return voltage appearing between the electrodes is then measured to assess the insulation's condition via the maximum spectra of recovery voltage and the recorded charging time [7-10].

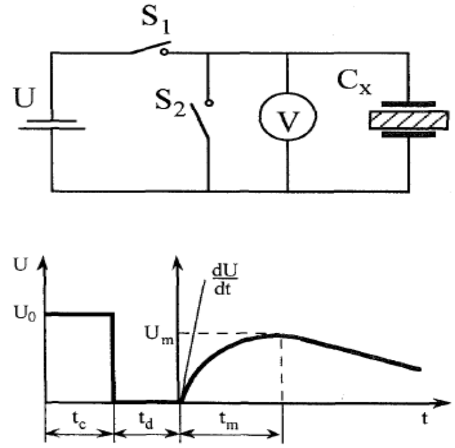


Figure 4 Return voltage phenomena

Hassan *et al*. [9] define the characteristics of return voltage measurement (RVM) into three. There are maximum value of return voltage (U_m), time to peak value (t_m) and initial increase rate of return voltage (dU/dt). Whilst Saha *et al*. define the parameters to be interpreted in return voltage measurement (RVM) as maximum return voltage, initial slope and central time constant [10]. Initial slope is the slope for first few seconds in return voltage graph whereas central time constant is the time at return voltage is maximum. Zaengl [5] defined the magnitude of return voltage is depends on charging time, t_c and at grounding period or discharging time, t_d. Initial slope of return voltage is proportional to the active depolarization current at discharging time and thus proportional to the intensity of polarization process.

Further, these two time domain dielectric response methods are able to measure by the equipment that have been developed by School of Information Technology and Electrical Engineering, University of Queensland. The equipment is known as Interfacial Polarisation Spectra (IPS) [2]. This system is integrated with computer-aided technique to control the hardware system. LabVIEW environment is adapted in the system that enables user to control the input of the parameters. It is fully automated system once it's operate. Measurement data then stored in the computer for future analysis. However, the evaluation of measurement data is done separately, generally using Matlab to define the condition of insulation system.

Another system been developed years later IPS. The commercially system is also fully automated with internal data evaluation, named as PDC Analyser 1 MOD by Alff Engineering.
Moisture content for paper can be obtained independently using RVM and PDC measurement while for oil based insulator, the results can only be obtained from PDC tests [7]. Saha *et al*. [7] thus introduced an expert system (ES) for the system operations and insulation diagnosis. ES which is a ruled based artificial intelligence technique has been applied by the aims at assisting the user to make unambiguous, reliable and quick decision in insulation condition assessment of the transformers using PDC and RVM techniques [7]. Krivda *et al*. [8] used Tettex RVM 5461 as an instrument to obtain polarisation spectra for RV measurement. Then, the measurement data been compared with the database in ES for the insulation diagnosis such as recognition the pattern for the obtained information.

3.0 RESULTS AND DISCUSSION

Ageing and degradation of high voltage equipment can be determined by the conductivity and moisture content of the insulation. These two parameters can be identified using PDC and RVM.

Figure 5 and Figure 6 represents the simulation of conductivities variation for oil and paper insulation studied by Saha *et al* [2]. They observed that moisture and contaminations affected the conductivity of both solid and liquid dielectric. Higher moisture tends to high the conductivity of insulator. It can be seen that higher conductivity for both solid and liquid insulation tends to higher the PDC curves.

Nevertheless, the conductivity for paper insulation is obtained at tail of PDC curves whereas the initial part of PDC curves is influenced by oil insulation. Thus, conductivity is a good indicator for determining the condition of insulator.

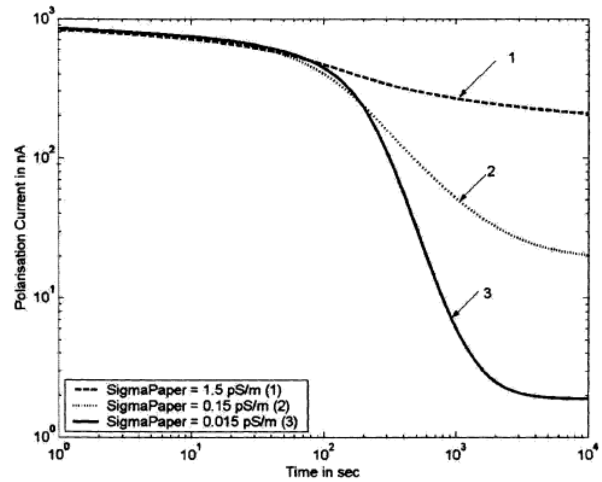


Figure 5 Polarization curves with variation of paper conductivities [2]

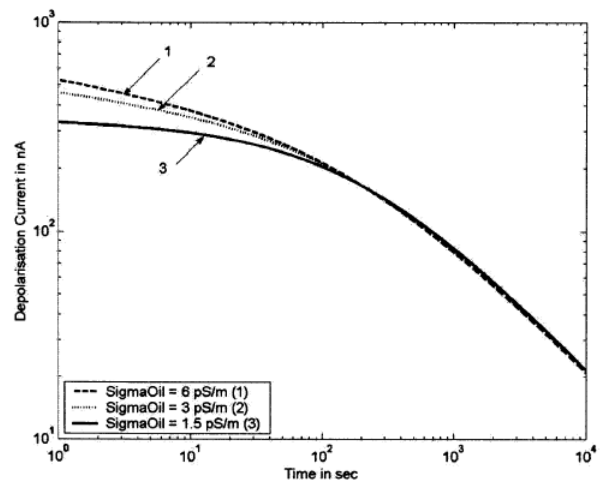


Figure 6 Polarization curves with variation of oil conductivities [2]

This is proven by the measurement that performed in six transformer with different apparent power(MVA), services record as well as the year of manufacturing. The transformer is characterized into three categories; A, B and C. The transformer details is tabulated in Table 1.

Table 1 Transformer details [2]

Transformer	MVA	Year	Service record
A1	7	1968	Lightly loaded
A2	30	1966	Suspected to be very aged
B1	100	1966	Before oil reclamation
B2	100	1966	After oil reclamation
C1	35	1936	Operating, but aged
C2	45	1959	Operating, but aged

Results for all transformer is been tabulated in Table 2 by comparing the transformer categories.

Table 2 Results for transformer categories

Transformer	PDC curves	conductivity	condition
A1A2	A1 < A2	$\sigma_{oil\ A1} > \sigma_{oil\ A2}$ $\sigma_{paper\ A1} > \sigma_{paper\ A2}$	A2 more degraded than A1
B1 B2 (same MVA and manufacturing year)	B1 > B2	$\sigma_{oil\ B1} > \sigma_{oil\ B2}$ $\sigma_{paper\ B1} > \sigma_{paper\ B2}$	B1 (before oil reclamation) are believed in an ageing condition
C1 C2	C1 > C2	$\sigma_{oil\ C1} > \sigma_{oil\ C2}$ $\sigma_{paper\ C1} > \sigma_{paper\ C2}$	Extremely degraded due to higher moisture content

Measurement of PDC is taken to the various types of field transformer. The results of simulation and field transformer is compatible to each other. Moisture content values is estimated and determine using Karl Fischer Titration method. Higher moisture content values affected the PDC curves to be higher too. Oil reclamation was performed to see the different condition of PDC curves; before and after oil reclamation. The most degradable insulator according to result in Table 2 is C1. Year of manufacturing and operation of the transformer also influenced the insulation condition of transformer. Since C1 is the aged transformer compared to other transformers, the previous excitation process leaved the precense of some amount of ions and paper. Distinguish between oil and paper insulation also can be obtained through PDC curves. Saha *et al*. [2] also recommend oil reclamation to improve the moisture condition for paper and oil insulation.

Krivda *et al*. [8] stated that polarisation process in oil-paper insulation is influenced by ageing and water content. Krivda *et al*. [8] used RVM to estimate the high voltage insulation system. The measurement conducted on several 130kV oil-paper current transformer that been used in transmission and distribution phase. Return voltage measured for main transformers and the capacitive tap insulation transformer. There are nine transformers with different manufacturing years and various history of services. They recognized return voltage measurement as a method to be used instead of tan δ to assess the insulation condition. Thus, expert system introduced by the information of polarisation spectra that obtained from return voltage. Polarisation spectra used as a primary source of pattern recognition information.

Frimpong *et al*. [11] also proven that changes in oil conductivity tends to affect the initial slope of return voltage (RV) (Figure 8) and paper conductivity affected the tail of RV such as in Figure 7.

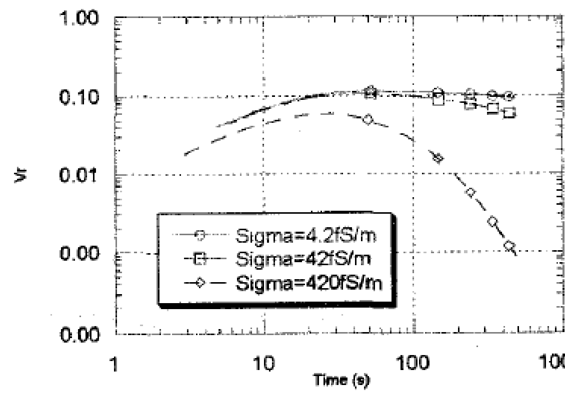


Figure 7 Variation of recovery voltage with paper conductivity [11]

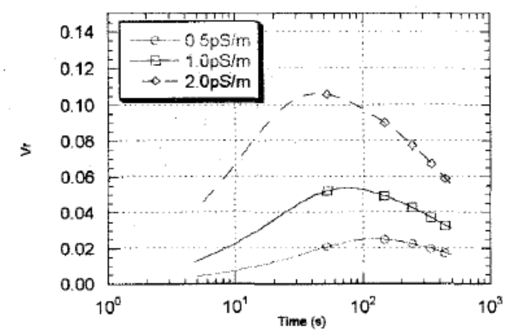


Figure 8 Variation of recovery voltage for oil conductivity [11]

Both figures showed that higher conductivity tends to higher the magnitude of return voltage (RV). Experiment conducted on the laboratory model of two cylindrical ducts that parallel to the measuring equipment.

Main parameters for pattern recognition are maximum value of return voltage, U_m, time to peak value, t_m and initial increase rate, dU/dt. Results from the research [8] define very bad condition after pattern recognition by expert system. Further, among the RV parameters, central time constant or also known as time to peak value, t_m was found to be most sensitive to ageing and moisture. but the oil and paper insulation cannot be evaluated separately. Whereas the polarization conductivity is proportional to the initial slope or initial increase rate, dU/dt of the return voltage for the transformer's insulation.

4.0 CONCLUSION

PDC and RVM is the dielectric response method that widely used in the area of condition monitoring. However, the simple and reliable method of analysis in assessing the insulation system as well as the ability to separate solid-liquid separately makes PDC measurement more advantageous than RVM.

Acknowledgement

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References

[1] E. Ildstad, *et al.* 1994. Relation Between Return Voltage and Other Methods for Measurements of Dielectric Response. In *Electrical Insulation, 1994., Conference Record of the 1994 IEEE International Symposium.* 25–28.

[2] T. K. Saha and P. Purkait. 2004. Investigation of Polarization and Depolarization Current Measurements for the Assessment of Oil-paper Insulation of Aged Transformers. *Dielectrics and Electrical Insulation, IEEE Transactions.* 11: 144–154.

[3] T. K. Saha and P. Purkait. 2003. Investigating Some Important Parameters of the PDC Measurement Technique for the Insulation Condition Assessment of Power Transformer. Presented at the International Power Engineering Conference, Singapore.

[4] N. A. M. Jamail, *et al.* 2011. Comparative Study on Conductivity using Polarization and Depolarization Current (PDC) Test for HV insulation. In *Electrical Engineering and Informatics (ICEEI), 2011 International Conference.* 1–6.

[5] W. S. Zaengl. 2003. Dielectric spectroscopy in Time and Frequency Domain for HV Power Equipment. I. Theoretical Considerations. *Electrical Insulation Magazine, IEEE.* 19: 5–19.

[6] T. K. Saha and P. Purkait. 2005. Impact of The Condition Of Oil On The Polarisation Based Diagnostics For Assessing The Condition Of Transformers Insulation. In *Power Engineering Society General Meeting, 2005. IEEE*. 2: 1881–1886.

[7] T. K. Saha and P. Purkait. 2004. Investigation of An Expert System for the Condition Assessment of Transformer Insulation Based on Dielectric Response Measurements. *Power Delivery, IEEE Transactions.* 19: 1127–1134.

[8] A. Krivda, *et al.* 1997. Assessment of Insulation Condition of 130 kV Oil-Paper Current Transformers Using Return Voltage Measurements and an Expert System. In *Electrical Insulation and Dielectric Phenomena, 1997. IEEE 1997 Annual Report., Conference*. 1*:* 210–213.

[9] O. Hassan, *et al.* 2003. Diagnostic of Insulation Condition of Oil Impregnated Paper Insulation Systems with Return Voltage Measurements. In *Electrical Insulation and Dielectric Phenomena, 2003. Annual Report. Conference.* 153–156.

[10] T. K. Saha and Y. Zheng Tong. 2003. Experience with Return Voltage Measurements for Assessing Insulation Conditions in Service-aged Transformers. *Power Delivery, IEEE Transactions*. 18: 128–135.

[11] G. Frimpong, *et al.* 1997. Measurement and Modeling of Dielectric Response of Composite Oil/Paper Insulation. In *Properties and Applications of Dielectric Materials, 1997., Proceedings of the 5th International Conference.* 1*:* 86–89.